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REGULATION OF SULFUR OXIDE EMISSIONS
FROM FEDERAL FACILITIES

Public Health Service
Washington, D. C.

November 1966

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REGULATION OF SULFUR OXIDE EMISSIONS ✓

FROM

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National Center for Air Pollution Control

U. S. Department of Health, Education, and Welfare
Public Health Service
Washington, D.C.
November, 1966

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INTRODUCTION

President Johnson, on May 26, 1966, issued Executive Order No. 11282 which requires that all Federal agencies take steps to prevent and control air pollution from their installations. Upon signing the order, the President noted that the most difficult problem encountered in its preparation was the lack of an economically feasible technology for controlling emissions of sulfur; and he added that a major part of the responsibility for sulfur research rests with the utilities, the coal and oil industries, and other groups which will feel the economic effects of more stringent air pollution regulations.

Regulations promulgated by the Secretary of Health, Education, and Welfare on June 2, 1966 (Federal Register Document 66-6201), pursuant to the Executive Order, state in 76.5(c)(1): "For Standard Metropolitan Statistical Areas or Standard Consolidated Areas whose central city has a population greater than 2 million and a population density greater than 15,000 persons per square mile, the Secretary will, within six months after the effective date of the regulations in this part, establish by regulation limits on the emission of sulfur oxides to the atmosphere or prescribe such control steps or measures as may be necessary over time to abate or control sulfurous pollution from Federal installations. The limits or measures so established shall be no less stringent than the relevant State or local requirements."

Listed below are the five central cities of metropolitan areas which meet either of these population criteria.

<u>City</u>	<u>Population 1960</u>	<u>Density Persons/square mile</u>
1. New York	7,781,984	24,697
2. Chicago	3,550,404	15,836
3. Philadelphia	2,002,512	15,743
4. Los Angeles	2,479,015	5,451
5. San Francisco	740,316	15,553

Los Angeles meets the population, but not the population density criterion; San Francisco, on the other hand, meets the population density criterion but has insufficient total population. Only New York, Chicago, and Philadelphia fall within both criteria and, hence, are subject to the quoted article.

However, the Secretary may at any time designate other urban areas which suffer from extremely high air pollution levels and, after consultation and publication, prescribe such limits or measures as he determines are necessary to carry out the intent of Executive Order 11282.

COMMUNITY AIR QUALITY GOALS

Department of Health, Education, and Welfare

The Department of Health, Education, and Welfare, although concerned primarily about air pollution's adverse effects on health and welfare, also is keenly aware of the broad economic implications of controlling sulfur oxide emissions from fossil fuel combustion. Major emphasis in its air pollution program is given to the search for low-cost techniques to deal with this particular problem. The Department has transferred funds to the Bureau of Mines to develop a process for selectively removing sulfur dioxide from stack gases and recovering valuable sulfur.

The Department has established as a goal for 1970 the development of technical and economic feasibility for controlling sulfurous emissions from fossil fuel combustion, so that broad policies may be adopted and implemented to prevent further increases in sulfur oxide concentrations and to reduce present levels of these toxic contaminants in critical urban areas. As interim steps towards these goals, the Department encourages greater use of low sulfur fuels in critical areas and preventive zoning to provide for remote location of high-sulfur fuel users.

Air and Local Agencies

Section 4 of Executive Order 11282 states in part, ". . . Federal facilities and buildings shall conform to the air pollution standards prescribed by the State or community in which they are located."

It is the Department's policy that Federal buildings follow exemplary practices in controlling pollutant emissions of all types and that the Federal Government provide continuity and leadership in the nationwide effort to control pollution. To ensure consistency with State and local regulations or standards, a review was made of control efforts and goals in the three metropolitan areas under consideration.

The City of New York, in 1964, promulgated regulations designed to reduce sulfur oxide discharges to the atmosphere by placing limitations upon the maximum sulfur content of fuel. A "Special Committee to Investigate Air Pollution" was appointed in 1965 by the City Council to establish the basis for a program of air pollution control that would result in prompt and substantial improvement in the quality of New York City's air. The Council Committee determined that existing regulations on sulfur emissions were inadequate to enable the City to reach desirable air quality objectives and recommended that the sulfur contents of fuels be reduced to one per cent over a period of nine years. Subsequently, the Mayor and others urged a shorter time period for compliance. After full consideration, the Council in May 1966 amended the Administrative Code of the City of New York to reduce the allowable maximum sulfur content of residual fuel oil and coal, in stepwise increments, to one percent over a five year period.

A May 1966 "Memorandum of Understanding," to which the City and the Consolidated Edison Company are both signatory, provides that the utility will present to the Mayor within six months, a plan for closing its power generating stations at Sherman Creek, Heli Gate, Kent Avenue,

and the older units at Hudson Avenue. In addition, major new power generating units will be constructed outside of the City.

The New York State Air Pollution Control Board and New York City Department of Air Pollution Control in September 1966 agreed that a single ambient air quality objective should be applied to New York City. The objective is 0.1 parts per million of sulfur dioxide for a 24-hour period, or 0.25 ppm for a 1-hour period, not to be exceeded more than 1% of the time on an annual basis. A public hearing by the Air Pollution Control Board is scheduled to consider this matter in November 1966.

The City of Chicago, in 1962, entered into a technical assistance agreement with the U.S. Public Health Service to plan and conduct a comprehensive air resource management program for the City. Objectives of this program included the preparation of a detailed inventory of actual and potential sources of air pollution, determination of the transport and dispersion of pollutants, improvement of the monitoring of pollutants, and devising a comprehensive plan for coping with present and future air pollution problems. Regarding sulfur dioxide, Chicago has pioneered in relating emissions to air quality. As the City develops more finite and specific data on the relationship between sulfur emissions and air quality, air pollution control decisions can be made and appropriate regulations developed.

The City of Philadelphia, in November 1965, expanded its air pollution control program to increase the effectiveness of existing legislation and to promulgate new laws and regulations that will improve the general air quality in the City. Regarding sulfur dioxide levels,

the City has recommended as a guideline that the desired concentration of sulfur dioxide should not exceed 0.06 parts per million averaged over a 24 hour period. The Council of Technical Advisors to the Pennsylvania Air Pollution Commission has recommended these criteria for sulfur dioxide:

- a. 0.15 ppm (24 hour samples) not to be exceeded more than once in any 100 day period.
- b. 0.30 ppm (1 hour samples) not to be exceeded more than once in any 100 consecutive hour period.

Desirable Air Quality

A great measure of success has been experienced by the coal industry and others in developing equipment and methods for the reduction of particulate emissions, which represent to the general public a form of air pollution with direct tangible effects on man and property. Gaseous pollutants generally are less perceptible to the average observer, but their effects on health and property--by themselves and synergistically, with particulate pollutants--are even more critical. Unless preventive plans and actions are undertaken now, total quantities and ambient concentrations of gaseous and particulate pollutants will increase sharply in the years ahead simply because of the explosive nature of urban energy requirements.

The principal forms of sulfur oxides in a polluted atmosphere are sulfur dioxide (SO_2), sulfur trioxide (SO_3), sulfuric acid (H_2SO_4), and sulfate salts (SO_4). The relative proportions of each compound may

vary with relative humidity, catalytic substances in the air, the intensity and duration of sunlight and other factors; but the proportions tend to remain roughly the same from year to year in any given area and, for convenience, sulfur oxide pollution concentrations usually are reported as sulfur dioxide. Since reductions in sulfur dioxide would result in concomitant reductions in the other sulfur compounds, sulfur dioxide is used in this analysis to establish desirable air quality levels and emission standards for Federal facilities.

Based on an intensive review of scientific studies on the effects of time-concentration exposures to sulfur dioxide, certain conclusions have been reached regarding desirable air quality objectives. Effects associated with sulfur dioxide pollution as it exists in the atmosphere with other pollutants in the lower concentration ranges are summarized below:

Concentration and Time

Effects

.02 to .03 ppm
for one year

1. increased respiratory disease death rates in humans.
2. corrosion of metals becomes significant.
3. injury to perennial vegetation.

0.1 to 0.3 ppm
for 2 to 4 days

1. increases in hospital admissions and mortality due to cardio-respiratory disease.
2. increases in prevalence of rhinitis, sore throat, cough and eye irritation.
3. mild to acute injury to sensitive vegetation.

0.3 to 1.0 ppm
for 1 hour or less

1. threshold for increased respiration and pulse rates of humans.
2. light sensitivity of the dark adapted eye increases 25 percent.
3. taste and odor threshold for humans.
4. threshold for traces of leaf injury to sensitive vegetation.

Based on the above effects, the Public Health Service has recommended to State and local agencies and has testified at Federal Power Commission hearings that sulfur dioxide concentrations for community atmosphere be maintained below the values indicated in Table 1. In large metropolitan areas, the longer averaging times would be the restricting ones, whereas in more rural areas with major point sources and very low annual mean values, the short-term peaks would be used to assure desirable air quality. Utilizing the lower concentrations and averaging times at which these different effects on various receptors begin to occur, a threshold curve of desirable air quality was prepared (Figure 1). Several states, cities, and other countries have evaluated and used the same or similar scientific literature as the basis for deriving air quality objectives and standards now in use. These also are shown in Table 1 and plotted on Figure 1.

Table 1. SULFUR DIOXIDE AIR POLLUTION STANDARDS AND OBJECTIVES

<u>Area</u>	<u>Standard or Objective</u>	
	<u>Concentration (ppm)</u>	<u>Averaging time (hours)</u>
California	0.3	8
	1.0	1
Colorado	0.1 not over 1% of time in 3 mos.	24
	0.5 not over 1% of time in 3 mos.	1
New York State The "objective" varies according to classified regions.	0.1 not over 1% of time	24
	0.15 not over 2% of time	
	0.25 not over 1% of time	1
	0.40 not over 2% of time	
Los Angeles, California	3.0 first alert	instantaneous
	5.0 second alert	instantaneous
	10.0 third alert	instantaneous
Dade County, Florida	0.1	8
	1.0	1/3
Manitoba, Canada	0.3	8
	1.0	1
West Germany	0.2	1/2
U.S.S.R. and Czechoslovakia	0.06	24
Poland	0.31	1/4
Rumania	0.09	24
Public Health Service	0.02 Annual mean	
	0.10 not to be exceeded more than one day in any 100 consecutive day period	24
	0.25 not to be exceeded more than 1 hour in any 4 consecu- tive day period	1
	0.50 not to be exceeded more than 5 minutes in any 3 consecutive hour period	1/12

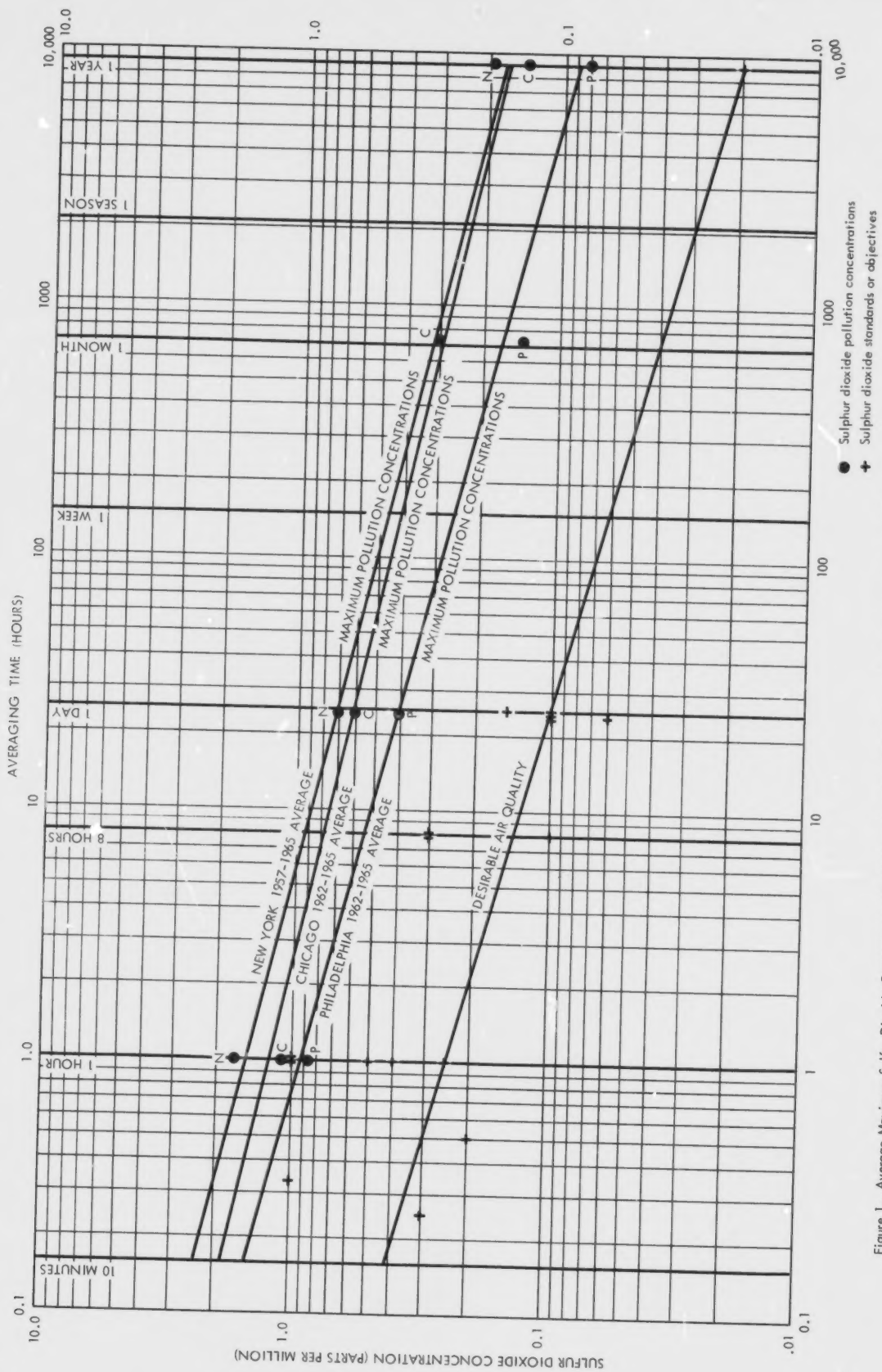


Figure 1. Average Maximum Sulfur Dioxide Concentrations by Various Averaging Times in New York, Philadelphia and Chicago Compared with Desirable Air Quality.

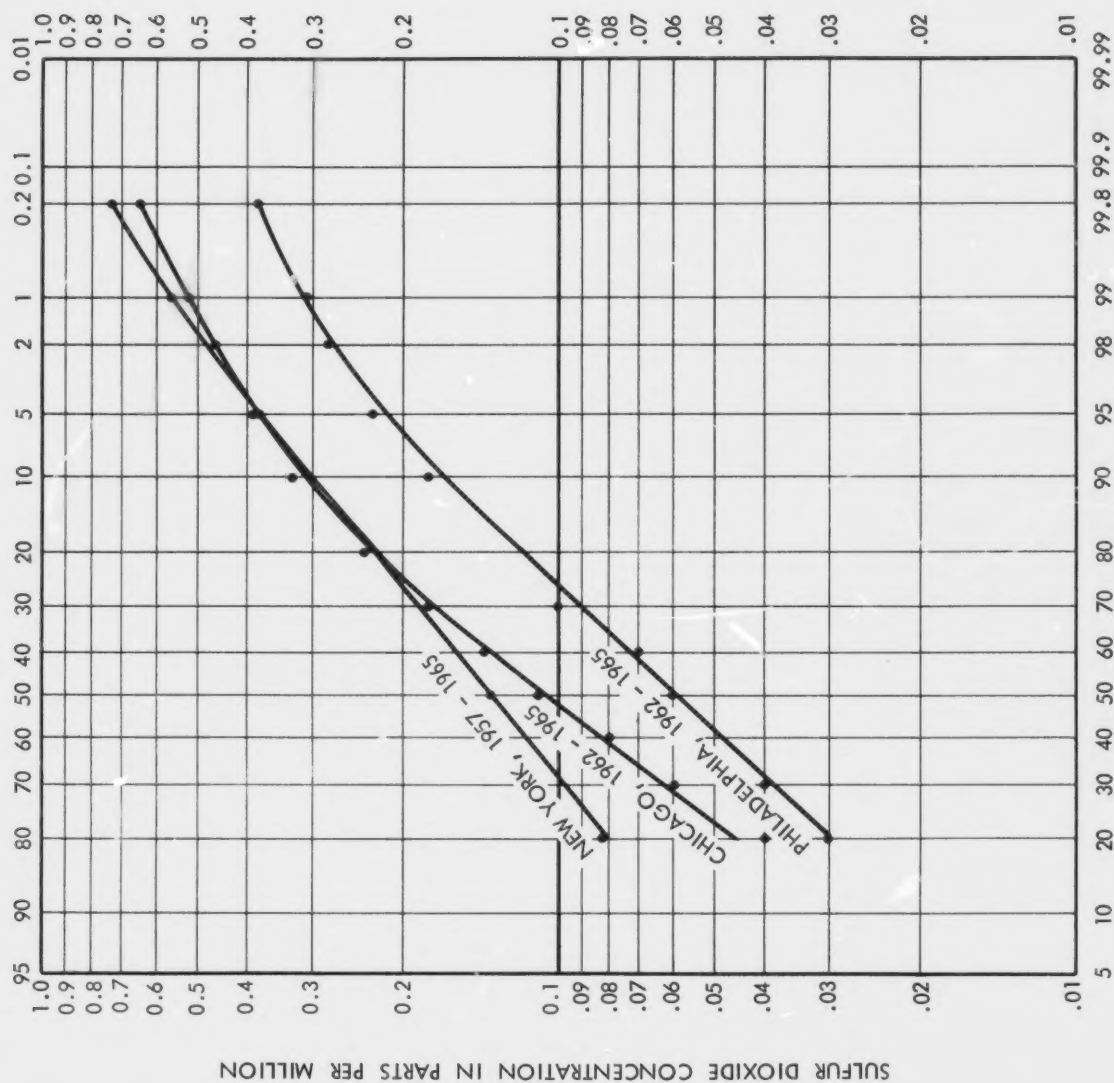


Figure 2. Frequency Distribution of 24-Hour Sulfur Dioxide Samples for New York, Philadelphia and Chicago.

CURRENT POLLUTION CONCENTRATIONS AND POLLUTION SOURCES

Existing sulfur dioxide concentrations in certain urban communities, including the three being considered here, far exceed the desired air quality curve. Air quality data from the Continuous Air Monitoring Program conducted by the U. S. Public Health Service in Chicago and Philadelphia and from the New York City Department of Air Pollution Control were reviewed and "average maximum" concentrations (shown below) were plotted for various averaging times (Figure 1). Frequency distributions of available data using a 24-hour averaging time are shown in Figure 2. Data representing four years of continuous sampling, 1962-1965, were analyzed for Chicago and Philadelphia, whereas nine years of data, 1957-1965, were used for New York.

Chicago Sulfur Dioxide Levels - ppm

	Average Annual	Maximum Month	Maximum Day	Maximum Hour
1962	.11	.24	.40	.89
1963	.15	.35	.79	1.36
1964	.17	.34	.68	1.09
1965	<u>.13</u>	<u>.27</u>	<u>.55</u>	<u>1.14</u>
Average	.14	.30	.61	1.12

Philadelphia Sulfur Dioxide Levels - ppm

	Average Annual	Maximum Month	Maximum Day	Maximum Hour
1962	.09	.13	.35	1.03
1963	.06	.15	.46	.85
1964	.08	.15	.43	.69
1965	<u>.08</u>	<u>.13</u>	<u>.36</u>	<u>.94</u>
Average	.08	.14	.40	.88

New York Sulfur Dioxide Levels - ppm

	Average Annual	Maximum Month	Maximum Day	Maximum Hour
1957	.20	not available	.55	2.0
1958	.16		.58	1.3
1959	.17		.64	1.2
1960	.18		.91	1.4
1961	.16		.69	1.4
1962	.19		.71	1.9
1963	.20		.85	1.5
1964	.24		.71	1.9
1965	<u>.21</u>		<u>.68</u>	<u>2.3</u>
Average	.19		.70	1.7

Pollution Sources

To identify the principal types and sources of sulfur oxide emissions in these areas, an emission inventory for 1965 was prepared for each metropolitan area (Tables 2, 3, and 4). In each of the areas, coal and oil combustion account for the bulk of sulfur oxide discharges to the atmosphere. In the New York area, the major source is residual fuel oil burned in commercial buildings, apartment houses and power plants. In the Philadelphia area, combustion of coal, combustion of oil and refinery emissions each contribute about equally. In the Chicago area, combustion of high sulfur coal, primarily by power plants, accounts for the bulk of the problem. Thus, meeting desirable air quality goals in each of these cities will require different emphases and procedures.

In the New York Standard Consolidated Area, 25 electric generating plants are responsible for 38 percent of the total sulfur dioxide. Because of the air conditioning load, emissions from these power plants are slightly higher in summer than in winter, with the peak

diurnal load occurring during the warmest hours of the day. Sulfur oxides from these power plants are discharged from stacks ranging in height from 250 to 500 feet. The next largest category, residential and commercial fuel use for space and water heating, together represents 45 percent. Fuel required for domestic water heating is estimated to amount to less than 30 percent of the total residential fuel use, so residential space heating in winter months accounts for most of this fuel. Sulfur dioxide from industrial heat and power consumption contributes 15 percent of the total. This low contribution reflects, in part, the nature of industry in the New York area as contrasted to some other parts of the country.

In the Philadelphia Standard Metropolitan Statistical Area, 10 major power plants and 4 small municipal electric-generating stations produce 37 percent of the total annual sulfur dioxide emission of some 740,000 tons. Peak loads follow the same seasonal and diurnal patterns as New York. Stack heights range from 150 to 320 feet. Next in importance are the six major oil refineries along the Delaware River, which account for 29 percent of the sulfur emissions. The other significant category is combustion of fuel for industrial heat and power which contributes one-quarter of the total. Both refinery and industrial emissions are rather evenly distributed over the year, with only small seasonal variations.

In the Chicago Standard Consolidated Area, combustion of bituminous coal for generation of electricity accounts for some 62 percent of the area's total sulfur oxide emission of 1,700,000 tons annually. While

most stacks of the 11 power plants are tall, up to 450 feet, ~~one~~ is equipped with "stub" stacks on the roof of the plant, 110 feet above the surrounding ground area. Industrial energy consumption accounts for 17 percent and residential and commercial sources together discharge 13 percent of the total sulfur oxides. Petroleum refining and manufacture of sulfuric acid account for 8 percent of the total emissions. Since 70 percent of the oil refining capacity and two large acid plants are located in one industrial complex--in the vicinity of two power plants, including the one with 110 foot stacks--sulfur oxide concentrations in that area are expected to be substantially higher than the levels found at downtown sampling sites.

Table 2. NEW YORK S.C.A.* - SULFUR DIOXIDE EMISSION INVENTORY - 1965

SOURCE OF EMISSION	% SULFUR	QUANTITY	SULFUR DIOXIDE EMISSION TON/YEAR	%
<u>Generation of Electricity</u>				
Coal, Bituminous	1.8-2.1	9,250,000 T.	620,000	38
Oil, Residual	2.3-2.4	36,200,000 Bbl.	340,000	
Gas, Natural	Negligible	107,700x10 ⁶ FT ³	280,000	
			Negligible	
<u>Industrial Heat & Power</u>				
Oil, Residual	2.5	22,600,000 Bbl.	245,000	15
Coal, Bituminous	2.1	1,227,000 T.	185,000	
Oil, Distillate	0.5	5,500,000 Bbl.	50,000	
Coke	Negligible	78,000 T.	10,000	
Gas, Natural	Negligible	Negligible	Negligible	
<u>Refining of Crude Oil</u>				
Capacity @		341,300 Bbl/day	40,000	2
<u>Residential</u>				
Oil, Residual	2.5	38,100,000 Bbl.	500,000	30
Oil, Distillate	0.5	51,900,000 Bbl.	315,000	
Coal, Bituminous	2.1	1,520,000 T.	95,000	
Coal, Anthracite	1.0	1,520,000 T.	60,000	
Gas, Natural	Negligible	172,000x10 ⁶ FT ³	30,000	
			Negligible	
<u>Commercial</u>				
(Assumed 50% of Residential)			250,000	15
TOTAL			1,655,000	100

* The Standard Consolidated Area is comprised of the following counties: Bronx, Kings, New York, Queens, Richmond, Nassau, Rockland, Suffolk, and Westchester in New York; Bergen, Essex, Hudson, Middlesex, Morris, Passaic, Somerset and Union in New Jersey.

Table 3. PHILADELPHIA S.M.S.A.* - SULFUR DIOXIDE EMISSION INVENTORY - 1965

SOURCE OF EMISSION	% SULFUR	QUANTITY	SULFUR DIOXIDE EMISSION TONS/YEAR	%
<u>Generation of Electricity</u>			<u>280,000</u>	37
Coal, Bituminous	2.1	5,607,000 T.	230,000	
Oil, Residual	2.5	6,124,000 Bbl.	50,000	
Gas, Natural	Negligible	3,380x10 ⁶ FT ³	Negligible	
<u>Industrial Heat & Power</u>			<u>182,000</u>	25
Oil, Residual	2.5	15,300,000 Bbl.	125,000	
Coal, Bituminous	2.1	1,340,000 T.	55,000	
Oil, Distillate	0.4	1,700,000 Bbl.	2,000	
Coke	Negligible	113,000 T.	Negligible	
Gas, Natural		95,600x10 ⁶ FT ³	Negligible	
<u>Refining of Crude Oil</u>	Capacity @	785,000 Bbl/day	<u>215,000</u>	29
<u>Residential</u>			<u>45,000</u>	6
Coal, Anthracite	1.0	710,000 T.	15,000	
Oil, Residual	2.5	2,010,000 Bbl.	15,000	
Oil, Distillate	0.4	10,030,000 Bbl.	15,000	
Gas, Natural	Negligible	68,410x10 ⁶ FT ³	Negligible	
<u>Commercial</u>	(Assumed 50% of Residential)		<u>20,000</u>	3
TOTAL			<u><u>742,000</u></u>	100

* The Standard Metropolitan Statistical Area is comprised of the following counties: Bucks, Chester, Delaware, Montgomery and Philadelphia in Pennsylvania; Burlington, Camden and Gloucester in New Jersey.

Table 4. CHICAGO S.C.A.* - SULFUR DIOXIDE EMISSION INVENTORY - 1965

SOURCE OF EMISSION	% SULFUR	QUANTITY	SULFUR DIOXIDE EMISSION TONS/YEAR	%
<u>Generation of Electricity</u>			<u>1,070,000</u>	62
Coal, Bituminous	3.5	15,311,000 T.	1,070,000	
Oil, Residual	1.3	13,000 Bbl.	Negligible	
Gas, Natural	Negligible	41,452x10 ⁶ FT ³	Negligible	
<u>Industrial Heat & Power</u>			<u>290,000</u>	17
Coal, Bituminous	2.8	4,000,000 T.	225,000	
Oil, Residual	1.3	15,400,000 Bbl.	60,000	
Oil, Distillate	.5	1,700,000 Bbl.	3,000	
Coke	Negligible	2,500,000 T.	2,000	
Gas, Natural	Negligible	205,000x10 ⁶ FT ³	Negligible	
<u>Refining of Crude Oil</u>	Capacity @	607,700 Bbl/day	<u>110,000</u>	6
<u>Manufacture of H₂SO₄</u>			<u>35,000</u>	2
<u>Residential</u>			<u>155,000</u>	9
Coal, Bituminous	2.5	2,530,000 T.	125,000	
Oil, Residual	1.3	8,000,000 Bbl.	20,000	
Oil, Distillate	.5	11,000,000 Bbl.	10,000	
Gas, Natural	Negligible	130,000x10 ⁶ FT ³	Negligible	
<u>Commercial</u>	(Assumed 50% of Residential)		<u>75,000</u>	4
TOTAL			<u><u>1,735,000</u></u>	100

* The Standard Consolidated Area is comprised of the following counties:
Cook, Du Page, Kane, Lake, McHenry and Will in Illinois; Lake and Porter
in Indiana.

REDUCTION NECESSARY TO MEET AIR QUALITY GOALS

Over 60 percent of the annual energy requirement for electricity, heat, and power in the New York Standard Consolidated Area is met by the combustion of 200 million barrels of oil---116 million barrels of residual and 84 million barrels of distillate oils. The remaining energy requirement is provided equally by coal and natural gas. Combustion of residual oil is estimated to produce 57% of the sulfur dioxide discharged to the New York atmosphere, whereas coal accounts for 31%, distillate oil for 10%, and the refining of crude oil for 2%. Combustion of natural gas produces essentially no sulfur dioxide.

Considering annual combustion of coal and oil, with a total heat content of 1,600 trillion British thermal units (Btu), approximately 1,600,000 tons of sulfur dioxide are emitted to the atmosphere. This is equivalent to 2 pounds of sulfur dioxide per million Btu. Existing sulfur dioxide concentrations need to be reduced 86% based on Figure 1, or 83% based on Figure 2, to achieve desired air quality*. The maximum allowable sulfur dioxide emission, using the lower figure, would be 0.35 pounds of SO₂ per million Btu. If this standard is to be met entirely by controlling sulfur content in the fuel, the maximum amount of sulfur by weight would be 0.3% sulfur in oil and 0.2% sulfur in coal**. If and when all power plants were to move out of the area, the required reduction of remaining sources would be 73%.

*Existing New York air quality (Figure 2) at the 99 percentile is 0.57 ppm. Subtracting the desirable air quality of 0.1 ppm gives 0.47 ppm which is a required reduction of 83% $\left(\frac{0.47}{0.57} \times 100\right)$.

**Heat contents of 145,000 Btu gallon of oil and 13,000 Btu per pound of coal are used throughout.

In the Philadelphia Standard Metropolitan Statistical Area, 43 percent of the total energy requirement is met by combustion of oil, 30 percent by coal, and 27 percent by natural gas. Sulfur dioxide discharged to the atmosphere is distributed among four principal sources as follows: coal - 40%, refineries - 30%, residual oil - 27%, and distillate oil - 3%. At the present time, coal and oil combustion produces 544 trillion British thermal units and 527,000 tons of sulfur dioxide annually. As in the New York area, this is equivalent to 2 pounds of SO_2 per million Btu. A 75% reduction based on Figure 1 or 68% reduction based on Figure 2 to achieve desired air quality objectives would require an emission standard, using the lower reduction of 0.65 pounds of SO_2 per million Btu. The maximum permissible sulfur content of fuel meeting this standard is 0.6% sulfur in oil and 0.4% sulfur in coal. If the steam electric plants' contributions were removed from the area, a reduction of almost 50% would be required of all remaining sources including the refineries.

In the Chicago Standard Consolidated Area, 48 percent of the energy need is met by coal, 32 percent by natural gas, and 20 percent by oil. Coal produces the bulk of the sulfur dioxide, accounting for 86% of the total. Refining of crude oil and acid manufacture together produce 8%, combustion of residual oil 5%, and distillate oil 1%. Coal and oil combustion of 930 trillion British thermal units produces some 1,600,000 tons of sulfur dioxide. This is equivalent to 3.4 pounds of SO_2 per million Btu. An 84% reduction based on Figure 1 or 81% reduction based on Figure 2 would allow 0.65 pounds of SO_2 per million Btu using the lower reduction figure. To achieve the desired air quality objective, fuels would be limited to no more than 0.6% sulfur in oil and 0.4% sulfur in coal. If the power plant

emissions were to be removed from the area's atmosphere, the required reduction of all remaining sources, including refineries and acid plants, would be about 50%.

Reduction using Emission Density and Multiple Sampling Stations

During 1965, the Chicago Department of Air Pollution Control used 18 air sampling stations to evaluate sulfur dioxide air quality and relate the data to emissions. Domestic and commercial fuel use appeared to be most directly related to local air quality even though industrial and power plant sources contributed to the measured levels. From Figure 3, a sulfur dioxide emission density of about 140 tons per square mile per year from domestic and commercial fuel users results in an average annual ambient air concentration of 0.02 ppm, which is the threshold value for desirable air quality using one year as an averaging time.

Presently Chicago has an emission density of 670 tons per square mile per year from residential and commercial sources thus requiring a 79 percent reduction. Considering only the relatively numerous domestic and commercial fuel users as sulfur dioxide sources, and applying the 79% reduction factor, an allowable sulfur dioxide emission of 0.70 pounds of SO₂ per million Btu is computed. This would indicate that the domestic and commercial sources are responsible for a proportionate share of the total ambient sulfur dioxide concentrations measured at local sampling stations.

While the Public Health Service Continuous Air Monitoring Program (CAMP) station measured air quality in the downtown commercial area, the 18-station network in Chicago was used to determine air quality throughout

the City and to evaluate the reduction necessary to meet desirable air quality. The 18 stations ranged from average annual concentrations of 0.03 in the suburban area to 0.11 ppm in the downtown area near the CAMP site, with an overall average of 0.05 ppm. Averaging all 18 sampling stations for Chicago during 1965, the 99 percentile level for 24-hour values was 0.26 ppm. To meet the 0.1 ppm desired air quality level would require an average reduction throughout the city of 62%. However, such a reduction would not provide the center city population with desirable air quality. To meet the desirable air quality of 0.02 ppm for the annual average at the downtown site would require an 82 percent reduction in the emissions of sulfur oxides. Hence, a close check of the previously calculated reduction of 81% is confirmed by three other methods.

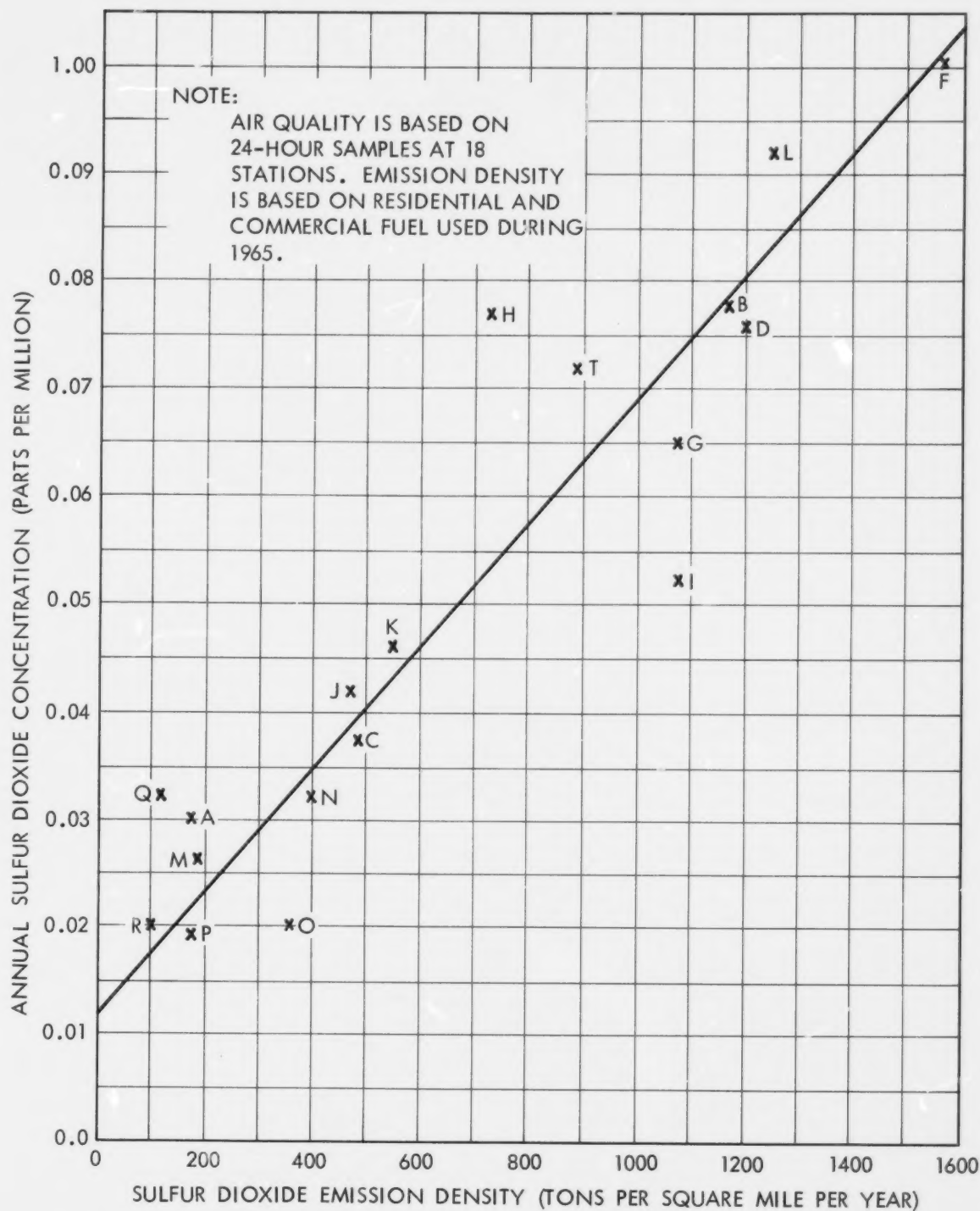


Figure 3. Relationship between Sulfur Dioxide Levels in the Ambient Air and Emission Density of Pollution Sources for the City of Chicago During 1965

CONSIDERATION OF STACK HEIGHTS

Diffusion in the Vicinity of Buildings

Many small Federal facilities have relatively short stacks, some of which discharge at or below the level of nearby windows or air intakes. Plumes from such short stacks are particularly subject to aerodynamic effects and can result in a low degree of diffusion and high effluent concentrations at nearby ground levels (Figure 4).

To study the diffusion phenomena in the vicinity of buildings under different micrometeorological conditions, an extensive series of wind tunnel experiments has been conducted at New York University. From this work, a generalized equation was derived to express downwind concentration of gas in the building wake when released above the roof (Figure 5):

$$c = K \frac{Q}{AV}$$

where: c = concentration of gas at a given point downwind in the building wake (ppm)

Q = rate at which SO_2 is released into an air stream (ft³/sec.)

V = average velocity of wind movement (ft./sec.)

A = surface area of the building perpendicular to wind direction (ft²)

K = concentration coefficient isopleth (dimensionless empirical value)

A sample calculation based on representative assumptions, illustrates the applicability of these principles in controlling emissions from Federal buildings. Assume:

1. Federal building with 100,000 square feet of floor area and a

60-foot square elevation perpendicular to the wind direction.

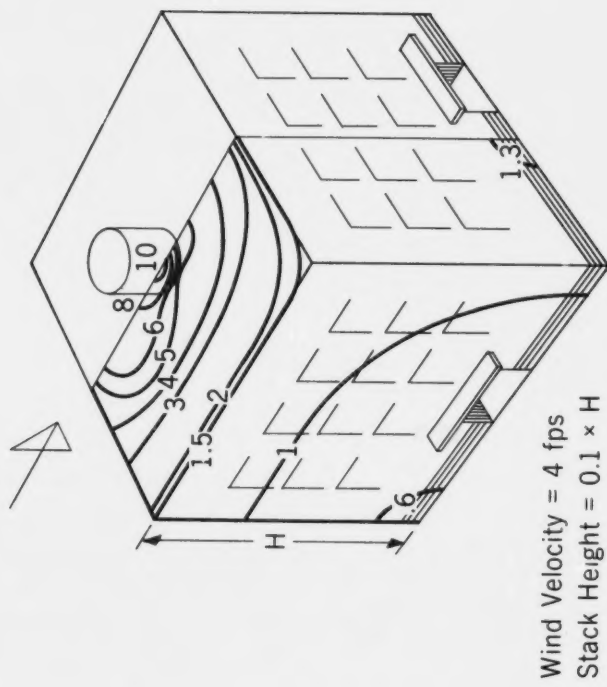


Figure 4
Isopleths of Concentration Coefficient K

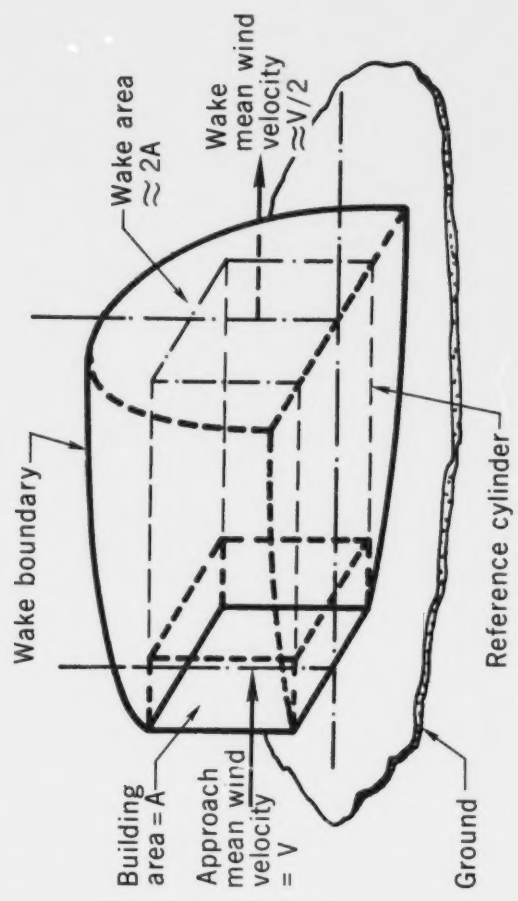


Figure 5
Average Gas Concentration in a Building Wake

(A = 10,000 ft²)

Wind velocity of 4 feet per second. (V = 4 fps)

The concentration coefficient, K, derived empirically.

(K = 1.0 dimensionless)

A maximum downwind concentration of sulfur dioxide gas at ground level in the building wake of 0.3 ppm, the taste threshold.

(C = 0.3 ppm)

Solving for Q gives a sulfur dioxide emission rate of 0.012 cubic feet per second or 7.3 pounds of sulfur dioxide per hour. To generate heat and hot water for this building would require about 10,000 pounds of steam per hour or 10 million Btu per hour; this amount of heat would be derived from approximately 770 pounds of coal, 70 gallons (550 pounds) of oil, or 10,000 cubic feet of natural gas. The maximum allowable sulfur content in the fuels to ensure that 0.3 ppm ground level concentration is not exceeded would be 0.47% sulfur coal or 0.66% sulfur oil. Natural gas would create no SO₂ problem.

Under other conditions, i.e., lower wind speeds, certain wind directions, unusual building configurations, location of the stack away from the center of the roof, turbulence from other buildings, etc., the SO₂ emission concentration might need to be reduced even further. However, if desirable air quality is to be achieved in the New York, Chicago, and Philadelphia areas, emissions will need to be limited to such a degree that downwash of plumes in the building wake will not pose a problem.

Dispersion From Tall Stacks

The relative importance of source height to ground level concentration was considered for Federal facilities to determine whether or not sulfur oxide emission limits should be modified for taller stacks. The average relative concentration over a city and the concentration at the downwind edge of the city were calculated for a theoretical city 40 kilometers on a side. A 2-kilometer grid of receptors and sources was assumed to be distributed throughout the area. Calculations were made for three meteorological conditions which would depict the weather in New York, Chicago, and Philadelphia areas at various times of the day for different seasons. Ratios of concentrations for combinations of three effective source heights are shown below. H is given in meters and all sources were assumed equal in strength.

Ratios of Concentrations - Heights in Meters

$$\frac{X(H = 30)}{X(H = 100)} \quad \frac{X(H = 30)}{X(H = 200)} \quad \frac{X(H = 100)}{X(H = 200)}$$

Mixing Height = ∞

Neutral stability

Average	2.2	6.72	3.2
Downwind edge	1.33	4.66	3.2

Mixing Height = 1000 meters

Unstable

Average	1.00	1.00	1.00
Downwind edge	1.01	1.07	1.04

Mixing Height = 250 meters

Slightly unstable

Average	1.11	1.30	1.17
Downwind edge	1.11	1.30	1.17

Low-level sources contribute most significantly to the average concentration over a city when stability is neutral or more stable than neutral. For unstable conditions, the average concentration is little affected by the source height. This also is true for slightly unstable conditions with a shallow mixing depth.

Sulfur dioxide peak values for New York, Philadelphia, and Chicago were reviewed to determine conditions responsible for maximum hourly and 24-hour results. Figures 6, 7, and 8 show the location and stack heights of major power plants in each area. In New York, 1964 maxima occurred most frequently with southwest winds and slightly stable air masses. The mixing depth of the air mass was sufficient so that emissions from tall stacks did not penetrate the mixing layer.

For Chicago and Philadelphia, the upper 2 percent of observations from the CAMP stations for the years 1962 through 1965 were analyzed for both 1-hour and 24-hour peaks. In Chicago, practically all 24-hour peaks were associated with the arrival of continental polar air masses. Extremely strong inversions in the morning hours weakened, but they continued throughout the day. Both 1-hour and 24-hour peaks were associated with southwesterly winds.

In Philadelphia, like Chicago, the peaks were associated with southwesterly winds and strong temperature inversions, but they showed no seasonal dependence. Both this evaluation and other studies by the City of Philadelphia and Drexel Institute of Technology indicate that the principal sources of sulfur dioxide are located southwest of downtown Philadelphia.

The relative importance of low-level sources versus high-level sources may be somewhat dependent on the size of the city, since the depth of the nocturnal mixing layer is a function of city size. In a small city, emissions from tall stacks rise above the average height of the nocturnal mixing layer and contribute little to ground level concentrations. In a larger city, emissions from tall stacks often are within the mixing layer (Figures 9 and 10) and contribute significantly to ground level concentrations.

In summary, large point sources contribute significantly to peak concentrations at ground level in downtown areas. However, present knowledge of the diffusion processes within an urban environment is not sufficient to derive a numerical formula setting emission standards for Federal facilities as a function of effective stack height.

NEW YORK S.C.A.

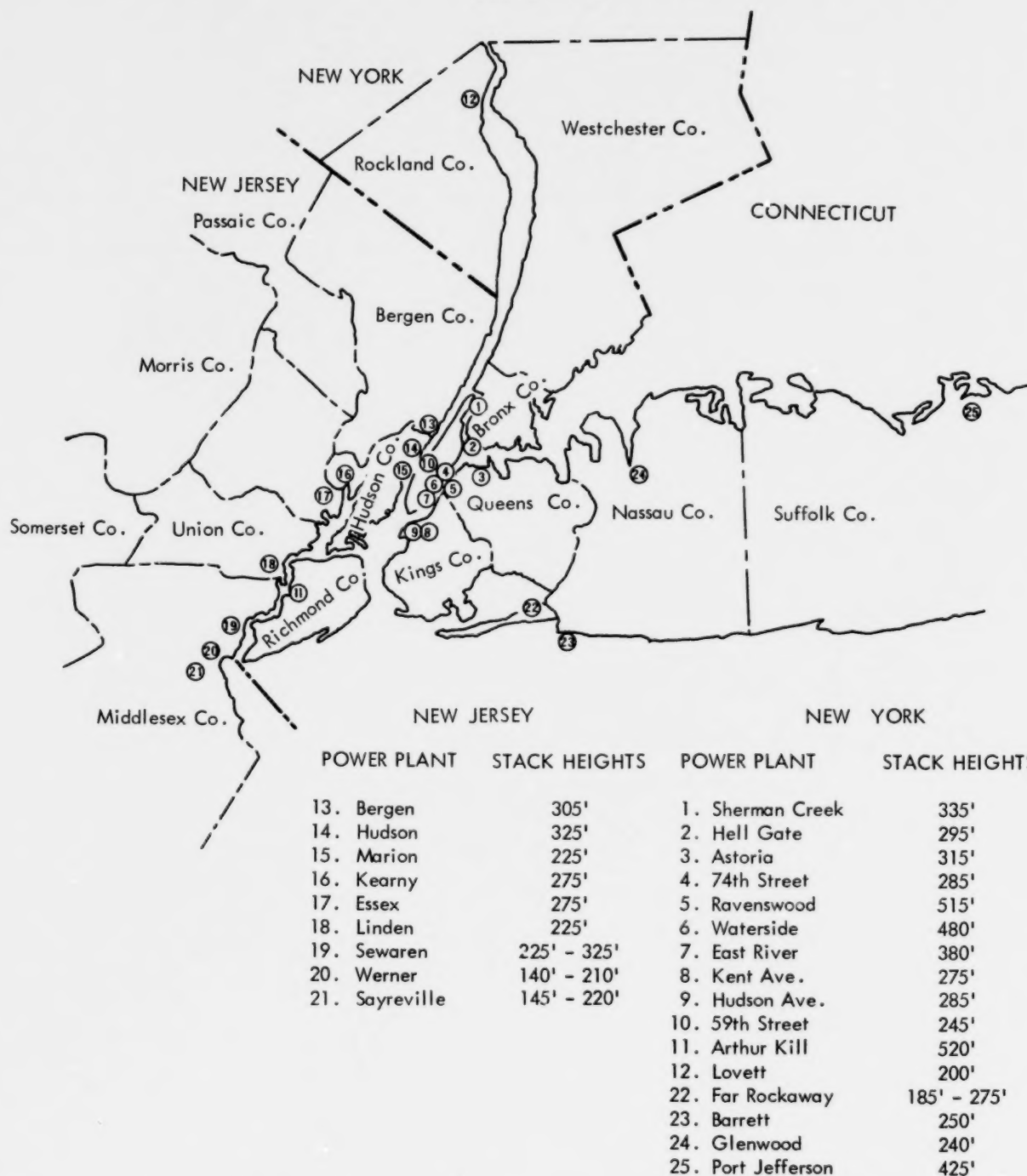


Figure 6. Location of Power Plants in the New York Standard Consolidated Area.

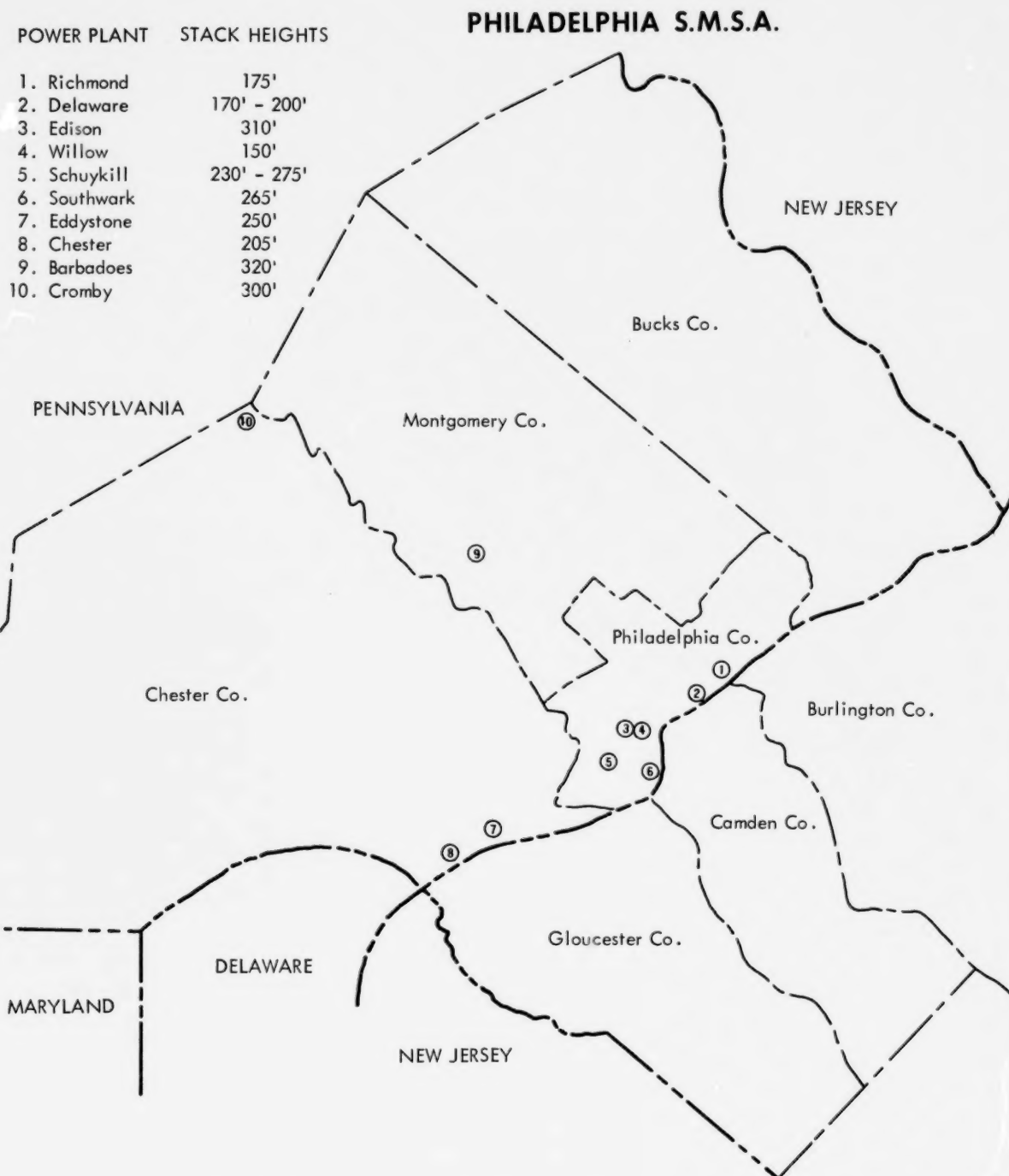


Figure 7. Location of Power Plants in the Philadelphia Standard Metropolitan Statistical Area.

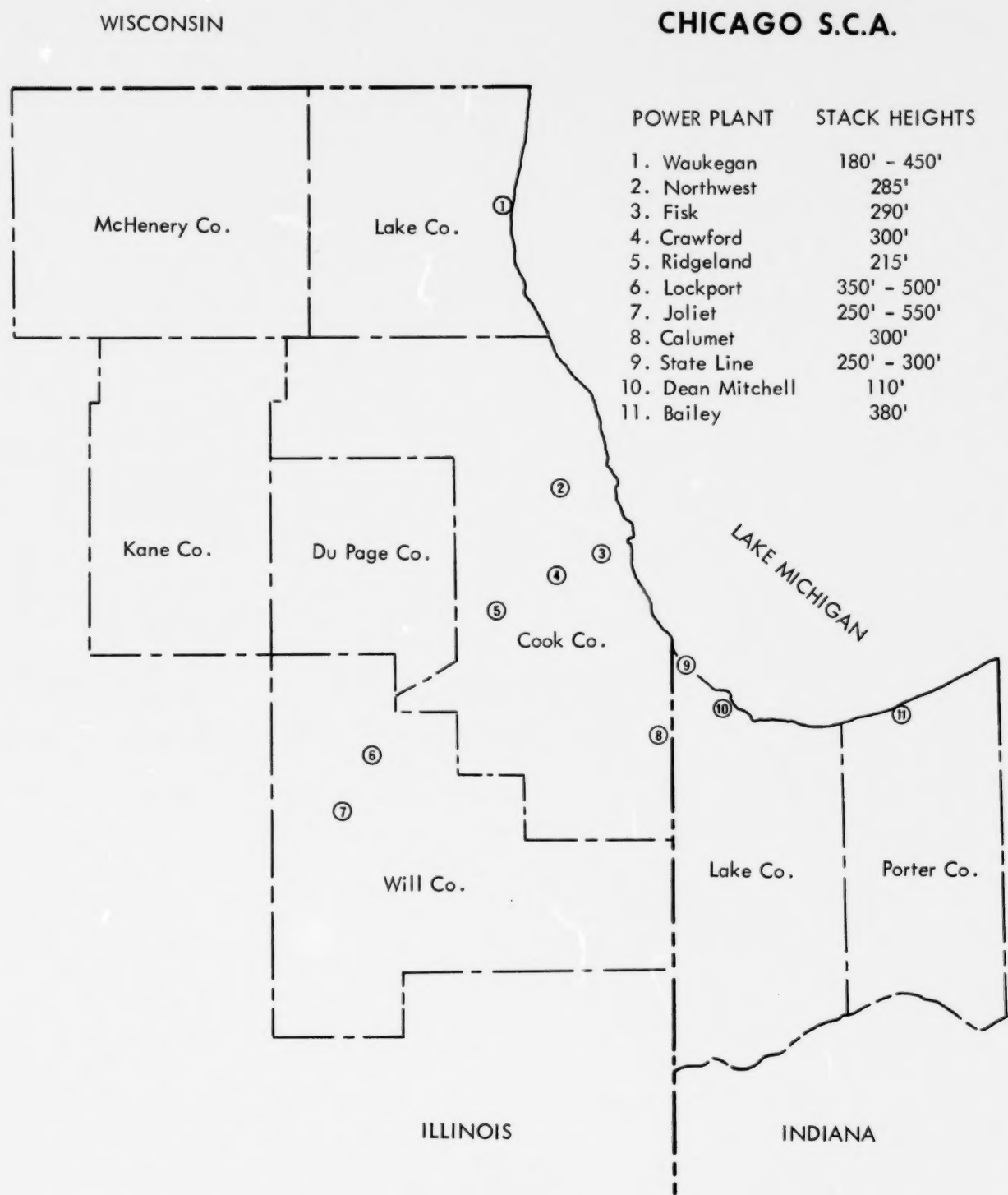


Figure 8. Location of Power Plants in the Chicago Standard Consolidated Area.

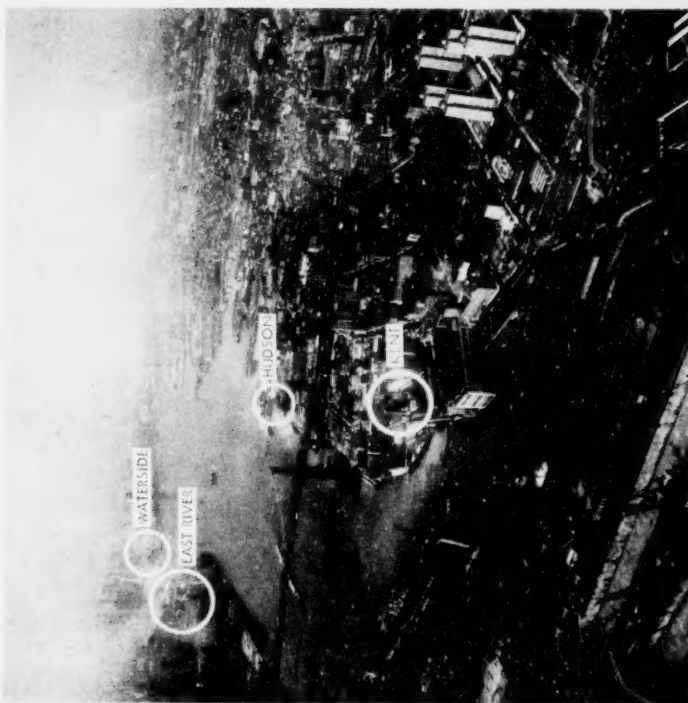


Figure 9. Four Consolidated Edison Steam-Electric Plants Are Indicated Above. The Stack Heights of the Plants Are: Kent - 277', Hudson - 387', East River - 378', and Waterside - 479'.



Figure 10. Manhattan Viewed from the Air over the East River. Note that Many Buildings Tower above the 479' Stacks of the Waterside Steam-Electric Plant.

Photographs by Sign X Labs, Inc.

SUGGESTIONS FOR RESOLVING THE SULFUR OXIDES PROBLEM FROM FEDERAL FACILITIES

On an annual basis, fuel burned in major Federally owned facilities of the three metropolitan areas totals 558,000 tons of coal and 2,210,000 barrels of burner oils. One-half of the coal, 287,000 tons, is consumed in the Chicago Standard Consolidated Area. In the three areas are located 156 Federal installations, 96 military and 60 civilian, each with 50,000 or more square feet of floor area:

City	Number of Installations	Coal Use tons/yr.	Oil use barrels/yr.	Sulfur Dioxide Emissions Tons/year
New York	81	155,000	880,000	9,000
Chicago	37	287,000	260,000	15,000
Philadelphia	<u>38</u>	<u>116,000</u>	<u>1,070,000</u>	<u>10,000</u>
	156	558,000	2,210,000	34,000

Assuming that sulfur contents of fuels used in Federal facilities are the same as other fuels burned in these Metropolitan Areas, the sulfur dioxide emissions from Federal facilities contribute only about one percent of the total sulfur dioxide emissions in each of the metropolitan areas.

The Public Health Service has established as one of its objectives and goals the substantial reduction of air pollution emissions from Federal facilities. For the Federal Government to meet its responsibility to be exemplary and to demonstrate leadership, alternative suggestions are outlined to illustrate the type and range of technical and administrative actions that can be taken to achieve desired goals.

Substitution, segregation, or blending of low-sulfur fuels is a practicable method by which sulfur oxides can be reduced from Federal facilities. High priority for the distribution of low-sulfur fuel rightly is given to small users since localized air quality has been found to be most directly affected by low stacks of nearby sources. It is administratively more efficient to maintain surveillance over a few large stacks than over thousands of small chimneys; other solutions are being sought for major point source problems.

Purchasers of fuel for Federal facilities should be advised that only 65% of mined coal is mechanically cleaned. Cleaning of coal at the mine, and segregation on the basis of sulfur content, would increase the available quantity of low sulfur coal.

Distillate grades of fuel oil used by small domestic and commercial users averages 0.4 to 0.5% sulfur; refiners could reduce the sulfur content of this distillate oil by 50% without an appreciable increase in price and sulfur oxide emissions from Federal facilities could be reduced concomitantly. Secondly, this low-sulfur material if blended and homogenized with "sour" residual oil, could make significant quantities of Grade No. 4 oil.

Natural gas is used extensively for large industrial plants and generation of electricity in portions of the United States; however, in the North and Eastern parts of the United States gas has been limited basically to domestic and commercial users, which would include most governmental requirements. Use of natural gas often has been justified for large industries or power plants which have low stacks or are

critically located with respect to susceptible receptors. Present gross withdrawals of natural gas exceed 17 trillion cubic feet, while known reserves of natural gas are estimated at 1700 trillion cubic feet.

Comparative costs of gas, No. 6 oil and street steam for space and water heating have been prepared for a typical Federal building with a volume of 1.5 million cubic feet in New York City. Use of centrally generated street steam for Federal facilities in downtown sections of urban areas would completely eliminate any direct Federal contribution to air pollution and, where such steam is available, the Government's heat costs probably would be significantly reduced.

Table 5. RELATIVE COSTS OF GAS, OIL, AND STEAM HEAT IN NEW YORK CITY

<u>Cost Item</u>	<u>Natural Gas</u>	<u>No. 6 Oil</u>	<u>Street Steam</u>
Investment Costs	<u>\$34,700</u>	<u>\$36,700</u>	-
Space Heating Boiler	24,200	26,200	-
Water Heating Boiler	3,000	3,000	-
Stack	7,500	7,500	-
Annual Operating Costs	<u>\$23,355</u>	<u>\$20,130</u>	<u>\$17,120</u>
Fuel	14,610	5,960	16,920
Labor	-	5,200	-
Maintenance & Supplies	375	450	200
Insurance	50	50	-
Value of Space	5,600	5,800	-
Amortization 30 yrs @ 6%	2,520	2,670	-

CONCLUSIONS AND RECOMMENDATIONS

1. The Department of Health, Education, and Welfare has recommended desirable air quality goals and objectives for sulfur dioxide that are consistent with those of involved local and State governments.
2. Present sulfur dioxide pollution levels in New York, Philadelphia, and Chicago greatly exceed desirable air quality levels and will continue to worsen unless corrective steps are initiated immediately.
3. The emission rate of sulfur oxides from combustion units of all Federal facilities or buildings in the New York Standard Consolidated Area should not exceed 0.35 pounds per million BTU calculated as sulfur dioxide. The emission rate of sulfur oxides from combustion units of all Federal facilities or buildings in the Chicago Standard Consolidated Area and the Philadelphia Standard Metropolitan Statistical Area should not exceed 0.65 pounds per million BTU.
4. Desirable air quality levels of sulfur dioxide will not be achieved in the New York, Philadelphia or Chicago area only by sulfur restrictions on the fuels used by Federal facilities. However, in view of the mandate in Executive Order 11282 directing all Federal agencies to provide leadership in the nationwide effort to improve air quality, it is essential that Federal facilities initiate fuel burning practices to reduce their contribution of sulfur oxide emissions for protection of the health and welfare of the people in these critical areas.

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